Crystal ladder filters

How to build low-cost s.s.b. filters using surplus crystals

by J. Pochet, F6BQP

This article gives design calculations for making crystal filters for s.s.b. applications and includes results of tests made on samples constructed by the author. The arrangement used in each case is that of a ladder filter where the crystals are connected in series. This very simple arrangement, see Fig.1, enables constructors to make low-cost filters, in comparison with commercial units, by using crystals having identical resonant frequencies.

The filters to be described in this article were made using 8314kHz crystals, as these were readily available to the author. The measurements were made in a laboratory with automatic instruments of high precision. Table 1 gives the results of measurements on one of the filters compared with the well-known XF9A filter. Definitions of the terms are shown in Fig. 2.

The results obtained from these tests are very satisfactory; the ultimate out-of-band rejection, better than 95dB, is excellent, the slopes of the sides of the filter are a little less steep than those of the XF9A, and the pass-band at −6dB is a little narrower. It should be mentioned that the measured characteristics of the XF9A filter are better than those claimed by the manufacturers.

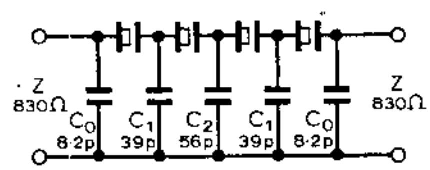


Fig. 1. Typical crystal ladder filter for 830 ohms impedance. In the ladder arrangement all the crystals, in this case devices having resonant frequencies of 8314kHz, are connected in series.

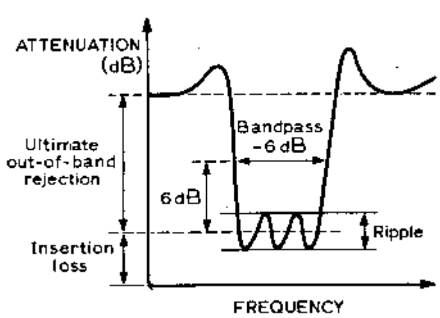


Fig. 2. Attenuation/frequency characteristic for a crystal ladder filter indicating the definitions used in the text.

Table 1 — Comparative results between a four-crystal ladder filter and the XF9A filter

	Ladder filter	XF9A filter
Insertion loss	1.4dB	2.5dB
Ripple	0.8dB	0.8dB
Bandpass:		
−3dB	1800Hz	2350Hz
−6dB	2050Hz	2540Hz
−20dB	2950Hz	3200Hz
−40dB	5200Hz	4250Hz
−50dB	6950Hz	4650Hz
Ultimate out-of-band rejection	>95dB	>48dB
Impedance	830 ohms	500 ohms

How to design the filter

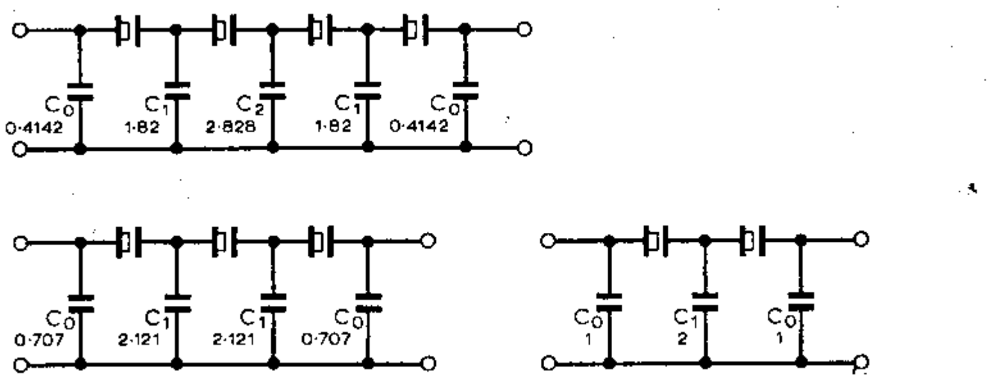
A filter of this kind can be made using two, three or four crystals in series. Fig. 3 gives the values of the capacitors as a function of the impedance and frequency values adopted. The choice of impedance is important because, in effect, the more this is reduced the more the pass-band is reduced and the higher will be the insertion loss. This is because the series resistance of the crystal becomes more significant in relation to the impedance.

On the other hand, if one chooses an impedance which is too high, the calculations will result in low capacitance values, and construction then becomes limited by the stray circuit capacitances.

In practice, for a frequency of about 8 to 10MHz, the impedance should be about 800 to 1000 ohms to obtain a pass band of 2100Hz, suitable for s.s.b.

It is necessary to underline the importance of the impedance of a filter, no matter what type is used. It is also of paramount importance that the filter should be correctly terminated because any significant mismatch could lead to a pass-band ripple of some 10dB.

Fig. 3. Typical crystal ladder filters. All crystals are of the same resonant frequency – preferably between 8 and 10MHz for s.s.b. units. The coefficients indicated against each capacitor should be multiplied by $1/2\pi fR$, where R is the design impedance and f is the resonant frequency of the crystal in hertz, to give the correct capacitor value. Three and four-crystal filters are capable of giving very good results. Two-crystal filters, although reasonably good, have relatively poor shape factors. See text.



It is possible to adjust the values of the capacitors; reducing them increases the passband but also increases the ripple in the pass-band (If a ripple of 2dB can be accepted, the passband can be increased by up to 20%). Note that it is advisable not to take advantage of this opportunity unless the necessary test instruments are available to check the results of any such adjustments (a wobbulator and oscilloscope are the ideal instruments for this type of adjustment).

The following is an example of how to calculate capacitor values for crystal ladder filters.

When R is the design impedance and f is the resonant frequency of the crystal in Hz, if f is 8314kHz, and R is 830 ohms, then $1/2\pi fR$ is equal to 23pF. From this one may obtain capacitor values for a four-crystal filter, as follows.

$C_0 = 0.4142 \times 23 = 9.5$pF (8.2pF)
$C_1 = 1.82 \times 23 = 41.8$pF (39pF)
$C_2 = 2.828 \times 23 = 65$pF (56pF)

and for a three-crystal filter:

$C_0 = 0.707 \times 23 = 16.3$pF (15pF)
$C_1 = 2.121 \times 23 = 48.8$pF (47pF)

and for a two-crystal filter:

$C_0 = 1 \times 23 = 23$pF (22pF)
$C_1 = 2 \times 23 = 46$pF (47pF)

The values in brackets refer to 10% preferred values.

These three filters have been built and the results obtained are shown in Table 2. In all three cases the passband ripple is less than a decibel. The results showed that with three or more crystals one may obtain a very good filter. Although the two-crystal filter gives a reasonably good out-of-band rejection (50dB), the sides are not very steep and the shape factor is modest. With a single crystal the out-of-band rejection is only about 20dB.

Table 2 — Measurements on two, three and four crystal ladder filters (for 8314kHz and 830 ohms impedance)

	Two crystals	Three crystals	Four crystals
Insertion loss	0.9dB	1.1dB	1.4dB
Bandpass:			
−6dB	2150Hz	2050Hz	2050Hz
−10dB	2700Hz	2350Hz	2250Hz
−20dB	4850Hz	3400Hz	2950Hz
−30dB	8900Hz	5050Hz	3900Hz
−40dB	16,100Hz	7500Hz	5200Hz
Ultimate out-of-band rejection	>50dB	>75dB	>95dB

Remarks

In the cases described above the passband extends from approximately 8314 to 8316kHz. The series-resonant frequency of the crystals therefore determines the lower limit of the passband; this is of interest since it is necessary only to use an additional crystal, of the same frequency as the others, for the carrier, to permit the selection of the upper sideband.

The choice of filter frequency depends on the availability of the crystals. It is possible to use frequencies from 5 to 20MHz, but if one has the choice it is preferable to use 8 to 10MHz. As an example, for a frequency of 5MHz it would be necessary to use an impedance of at least 1500 ohms in order to obtain the necessary bandwidth for s.s.b.

By using a lower frequency and lower impedance, it is possible to make an excellent c.w. filter.

The filters described above could be constructed on a p.c.b. and fitted into a small metal box, which should be connected to ground to avoid stray leakages.

An example circuit arrangement

Let us finish with an example of a circuit arrangement allowing the filter to be inserted at points of impedance equal to its own. This circuit is shown in Fig. 4. The output impedance of the first stage is practically equal to the collector resistance of Tr_1 (common emitter configuration) and the input impedance of the second stage (Tr_2 in common collector configuration). In this way the correct termination of the filter is obtained with the advantage of a very low output impedance (that of Tr_2), suitable for connection to the mixer on transmit and the i.f. stage on receive.

This circuit could also be very useful for measuring the filter's response curve with a sufficiently stable h.f. generator, a digital frequency meter and a voltmeter incorporating an h.f. probe, or better still a wobbulator.

In conclusion the author recognizes that it would be interesting to study this technique further; trying for example readily-available surplus FT243 crystals, or low-cost 27MHz crystals having 9MHz fundamentals.

Pat Hawker comments: This is a free translation of an article, "Essais, mesures et realisation de filtres a quartz" by J. Pochet, F6BQP, published in *Radio-REF*, journal of the Reseau des Emetteurs Francais, in May 1976. For many years the vast majority of crystal bandpass filters used in h.f. communications have been based on the half-lattice or lattice configuration, plus some limited use of the bridged-T approach. The recent use of higher frequency filters, particularly around 5, 9 and 10.7MHz has opened the way to greater use of the attractive ladder filter. At these frequencies it is possible with three or four identical frequency crystals and with practical values of impedance and capacitors to achieve passbands of between 2 to 3kHz, reasonably good shape factors and high ultimate out-of-band rejection.

While it would seem possible to obtain better shape-factors and ultimate rejection by using more crystals, this will usually require careful adjustment of capacitor values and is less easy to arrange in a symmetrical form having equal input and output impedances.

Fig. 4. One method of connecting a crystal filter into a transceiver circuit to ensure correct impedance matching. See text.

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